**US Army Corps
of Engineers**
**Construction Engineering
Research Laboratories**

REMR Management Systems—Navigation Structures: A Simple Condition and Performance Rating Procedure for Riverine Stone Training Dikes and Revetments

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19981103 047

Prepared for Headquarters, U.S. Army Corps of Engineers

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Preface

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
sq feet	0.0929	sq meters

1   Introduction

Background

The U.S. Army Corps of Engineers (USACE) is responsible for the maintenance of the United States inland waterways navigation system. Facilities in the Army Corps Civil Works program support flood control, environmental stewardship, recreation, and hydropower generation. The Corps constructs and maintains multi-purpose structures that support the Civil Works missions. The Repair, Evaluation, Maintenance and Rehabilitation (REMR) Research Program is working to discover and develop technologies that will extend the service life of Corps Civil Works structures. Two key missions in the navigation arena are stabilizing the banks and maintaining navigability of inland rivers.

The U.S. Army Construction Engineering Research Laboratories (USACERL) is conducting research under the REMR program in the Operations Management problem area. Within this area researchers are developing methodologies to provide consistent and objective condition assessment procedures for Civil Works structures. Such procedures, coupled with microcomputer-based database management, provide decision support for cost-effective planning of REMR type activities for Civil Works facilities.

A REMR Management System consists of condition inspection procedures, condition rating systems, data analyses, database management, and automated reporting. The key to cost-effective maintenance is a good understanding of a facility's current condition and an ability to predict future condition. The REMR Management System attempts to quantify a structure's condition and allows storage and manipulation of the data in a computer.

Objective

This report describes a simple algorithm that provides a quantitative description of the condition of riverine stone navigation training dikes and revetment. The quantitative description, called a condition index (CI), is incorporated into a REMR Management System for stone navigation training dikes and revetment. The software part of the REMR Management System for training dikes is described in REMR OM-23, *Dike and Revetment Condition Index Software User's Manual.*

Scope

The Corps oversees the maintenance and repair (M&R) of thousands of river bank stabilization structures such as dikes, revetments, weirs, dams, and levees. The Corps maintains an inventory of nearly 11,000 riverine training dike structures (Derrick, Gernand, and Cruthchfield 1989). This report addresses the condition assessments of existing stone dikes and stone dikes that will be constructed in the future.

A dike is defined here as a riverine training structure that is often rooted to the river's bank. Its length is approximately perpendicular to the river's flow. The dike maintains channel navigability by constricting the channel's width and increasing velocity (at the channel end of the dike). Dikes have many forms of construction and configuration. When dikes are parallel to the bank or flow direction, they are often called revetment structures. Dike nomenclature varies widely from district to district. This report defines nomenclature that conflicts with common usage in other districts (see Appendix D).

2 REMR Management Systems

History

The demonstrated success of Engineered Management Systems (EMS) such as PAVER and ROOFER (Shahin and Kohn 1981; Shahin and Bailey 1987) as decision-support tools for cost-effective maintenance management prompted the development of such systems for Civil Works. Good maintenance practice originates with accurate information about a structure's current and future condition. Current efforts focus on inland navigation structures, such as locks, dams, retaining structures, and river training structures (Greimann, Stecker, and Rens 1989; Greimann, Stecker 1989; Bullock 1989), flood control structures such as embankment dams (Foltz 1998, temporary number REMR OM-123), and coastal structures (Plotkin 1996).

REMR Systems Overview

Fundamental goals of the REMR Management System are to establish Corps-wide inspection uniformity and to establish common definitions of condition so that more effective communications concerning condition can be made. REMR Management Systems use uniform condition inspection techniques that emphasize visual, inexpensive, and efficient methods of data gathering.

At the heart of a REMR Management System is the Condition Index (CI). The CI is a number ranging from 0 to 100 and is an indicator of a structure's condition and, to some extent, its functionality. The CI is obtained from an algorithm that uses field inspection data as input and is designed so that it provides consistent, repeatable, uniform results. The consistency of the CI allows comparisons of the relative conditions of similar structures and trends in condition over time. With sufficient data and applied analyses it may be possible to develop curves allowing the

projection of physical deterioration of a structure based on current or expected operating conditions. The CI is described in detail in the next section.

In addition to the obvious benefits of a consistent, repeatable, uniform method of condition description, the REMR Management System offers other benefits. Life-cycle cost analyses can be examined with CI data. Various M&R strategies showing cost and expected condition levels can be compared. The microcomputer-based system is used to track inventory, inspection data, and maintenance history and to provide automated output such as condition reports, repair estimates, and materials quantity estimates.

The REMR Management System does not dictate where, when, or how M&R will be performed. The system is a decision-support tool that can help managers and planners prepare budgets and M&R schedules.

3   Condition Index

The CI Scale

Table 1 shows the REMR Condition Index Scale. The scale is divided
into three Recommended Action Zones and seven Condition Description
Areas. The scale is universal and can be referred to for the CI of any
structure. The CI should provide an accurate picture of the condition of a
structure. It is not intended to flag a structure for immediate repair but
rather to give an immediate, objective assessment of the structure's
condition. The CI is a gauge of the physical deterioration of a structure
and removes the subjectivity from condition descriptions.

The CI ranks structures on their condition level and not according to
hierarchical criteria. For example, if two structures are in identical
condition but the consequences of failure for one far exceeds that of the
other, their respective CIs are still the same. The CI is a "snapshot" of
condition. For grades of Poor, Very Poor, and Failed the recommended
action calls for more detailed analyses to determine the nature of the
deterioration and the appropriate response. The CI gauges physical
deterioration but does not govern M&R actions.

Forming A Condition Index Algorithm

The most important tool used to formulate a CI algorithm is expert
opinion. The CI algorithms vary according to the type of structure but the
scale used to describe the condition does not vary. Expert opinion is
obtained by interviewing field personnel responsible for the M&R of a
given type of structure. A consensus is formed on what factors affect a
structure's condition and functionality. Only condition criteria are used to
determine the need for repair. Certainly there are more abstract factors
that must be considered in determining the need for repair, but the CI is
designed specifically to gauge the physical deterioration of a structure.

The CI algorithm is designed to be consistent with the REMR Condition Index Scale (Table 1). Any mathematical variety of formulas or equations may be used. The algorithm uses data that are readily available from visual inspection or simple measurement. The CI is designed to be meaningful to the engineers who are responsible for the structure. The procedures for obtaining a CI are field-tested for reliability and repeatability before being adopted.

Table 1. The REMR Condition Index Scale.

Zone	Condition Index	Condition Description	Recommended Action
1	85 to 100	Excellent: No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	Good: Only minor deterioration or defects are evident.	
2	55 to 69	Fair: Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	Marginal: Moderate deterioration. Function is still adequate.	
3	25 to 39	Poor: Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	Very Poor: Extensive deterioration. Barely functional.	
	0 to 9	Failed: No longer functions. General failure or complete failure of a major structural component.	

4   Research Approach

Coordination With Waterways Experiment Station

A literature search of REMR Technical Reports (Derrick, Gernand, and Crutchfield 1989; Derrick 1991a and 1991b; Pankow and Athow 1986) led to initial contact with the U.S. Army Waterways Experiment Station (WES) in Vicksburg, MS. The initial point of contact was Mr. Dave Derrick (CEWES-HR-RR). A meeting with Mr. Derrick provided an overall view of the Corps Master Plan for inland waterways bank stabilization and the various types of riverine training structures that are used to achieve it. Early training structures were constructed of timber pile or wicker mats but nearly all modern training dikes are made of stone.

Many districts are still in the new construction phase of the Master Plan and are not expected to complete their projects until 2010. However, Missouri River Division and Southwestern Division have completed their projects and have been in the maintenance mode since the early 1980s. A review of the Corps' riverine training structures inventory targeted site visits for districts managing the most structures.

Interviews With District Personnel

Points of contact were identified in six districts and personnel responsible for the M&R of training structures were interviewed. A list of the people present at each interview is given in Appendix A. When possible, field trips were taken to see the dikes. The interviews focused on what criteria was likely to prompt dike repair. The level of dike M&R activity varied across the districts, ranging from considerable to almost nonexistent. Most of the districts do not use uniform inspection procedures. Inspection procedures varied from aerial photography to telephone calls reporting damage from commercial and recreational river traffic. In most cases, periodic inspections are performed and damage is recorded free-hand in a notebook using no specific format.

A separate group of engineers met to devise a CI algorithm that will gauge the deterioration of dike and revetment structures. Each person in the group is considered an expert on M&R requirements for dike and revetment structures. Results were tested in field exercises and the CI tables were graded and refined according to the results from the field. The members of this technical review group are given in Appendix B.

5 Condition Index Algorithm

Stone Training Dike and Revetment—Condition Index

Several factors are considered when prioritizing dike maintenance. Table 2 was constructed using data from REMR Technical Reports (Derrick 1991; Pankow and Athow 1986) and information from interviews with USACE personnel. The interviewees are responsible for the M&R of riverine training structures and represent six Districts across three Divisions: CELMVD, CESWD, and CEMRD. A blank field in Table 2 indicates the associated District did not specifically cite the distress or reveal the repair criteria in either the references or interviews.
All of these factors play an important role in the M&R decisionmaking process, but only five can be directly ascribed to a dike's condition in determining a CI. (Remember, the CI is a "snapshot" of condition and functionality, not an indicator of a structure's hierarchical importance.) The five factors are: entire dike missing, flanking, loss of grade, holes, and adequacy of navigation. Each factor and its associated contribution to a dike CI is described below.

The scheme for producing an overall dike CI is to consider first each distress in its own regard, as if it were the only factor affecting the dike's condition or functionality. A CI is calculated for each category of distress. The minimum CI value is then assigned to the dike. This simple approach is consistent with the maintenance policy that each of these distresses is an equally important condition-related criteria in determining the need for repair. A scheme that uses a weighted average of all noted distress would tend to obscure the contribution of one of the distresses that may be critical.

Table 2. Training Dike Distress and Repair Criteria.

REPORTED DISTRESS	CEMRK	CESWL	CELMM	CESAM	CEMRO	CENCR	CELMS	CENCS	CESWT	CELMK
Loss Of Grade > 2'	X	X	X		X	X	X	X	X	X
Flanked	X	X	X	X	X	X	X			X
Loss Of	X			X	X		X	X		X
Breach - Hole > 100'	X	X	X	X	X		X	X	X	X
Excessive Scour	X	X	X		X		X			X
Bank Scallops			X						X	
Entire Dike Missing				X	X	X	X			
Loss of Marker Pile							X		X	X

REPAIR CRITERIA	CEMRK	CESWL	CELMM	CESAM	CEMRO	CENCR	CELMS	CENCS	CESWT	CELMK
Project Integrity	X					X	XXX			
Flanking	XXX	XXX	XXX	XXX	XXX		XXX		XXX	XXX
Loss of Grade > 2'	XXX	XXX	XXX	XXX	XXX		X		XXX	XXX
Breaching / Holes	XXX				XXX		XXX		XXX	XXX
Adequacy of Navigation	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Serious Bank Erosion	XXX	XXX			X		XXX		XXX	XXX
Integrity of Structure	XXX	X	X	X	X	X				X
Dike Field Integrity	XXX				X	X	X			XXX
Environmental Impact	X	X	X	X	X		X		X	X
Extent of Damage	XXX		XXX		X	XXX	XXX		X	XXX
Location of Structure	X	X		XXX	X	X	XXX		X	XXX
Type of Structure	XXX				XXX					
Available funding	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX

XXX - Indicates Repair Criteria Is Deemed More Significant

It may be noted that while all riverine dike and revetment structures are partially, if not completely covered with water, the distresses described include effects that would be detected if the base of the structure were eroding. Tables 3 and 4 show the CI values associated with each distress and the algorithms used to arrive at the CI for the given structure.

ENTIRE DIKE MISSING: It is possible to lose entire dike structures because of such events as floods, ice damage, or towboat impacts. Clearly, the only acceptable CI for such complete damage is zero, $CI_{Exist} = 0$.

FLANKING: Flanking occurs when the entire dike is overtaken by the river. Flanking usually happens within 5 years of initial dike construction. (Scouring develops in the water on the downstream side of the dike while the river bank is scooped out, or "scalloped," until the root end of the dike is completely engulfed in water from the landward end.) Generally, a flanked dike is repaired immediately if the dike is critical to channel navigability. A flanked dike is assigned a CI of 39, to bring the dike to a zone III on the REMR CI Scale, $CI_{Flanking} = 39$. (Note: Structures such as vane dikes, chevrons, and windrows have no bank connection and, therefore, are not subject to flanking. Flanking is not considered in determining the CI for these structures.)

LOSS OF GRADE: Refer to Table 3 for appropriate $CI_{LossGrade}$ values. Loss of grade can occur due to settling within the first 2 years of initial construction. Loss of grade can also occur through loss of stone due to ice, floods, towboat impacts, weathering, or other causes. Loss of grade in some cases may not diminish channel navigability and, therefore, is ignored sometimes. However, most districts report that a loss of grade more than 2 ft over distances exceeding 100 ft are usually brought back up to grade by adding stone. Several degrees of grade loss are addressed within the algorithm. The CI values vary according to the degree of grade loss, the location along the length of dike, and the location of the distress relative to the shore line. (Grade loss is more dangerous when it occurs closer to the bankline rather than closer to the river end.) The gradation of CI values in Table 3 represents a gradual loss of grade, starting at 2 ft lost over 100 ft length, and increasing in severity, with some uniformity from there. For any loss of grade greater than 4 ft over any distance, the CI will

be at the bottom of Zone II of the REMR CI Scale. For dikes with multiple instances of grade loss, the dike CI is the minimum of the CIs calculated by the equations presented in Table 3.

HOLES: Some holes are intentionally placed in dikes to enhance wildlife habitat on the downstream side of the dike. The holes are called environmental notches and are not dike distresses. They do not detract from a dikes overall CI. In reference to the breaching holes described in Table 2, after discussion by the expert panel, it was deemed appropriate that "holes" were actually concentrated losses of grade and should be treated as such.

BANK SCALLOPS: Scouring effects can occur both upstream and downstream from a dike structure for a number of reasons (e.g., a neighboring structure causes an eddy effect). The river "scoops out" the bank above or below the bank connection. Eventually, if left alone, the scallop may allow the river to flank the dike. The algorithm ranks scallop distress severity based on the location and dimension of the scallop(s) relative to the dike. The CI assigned to scallops is lower when there is a greater likelihood of losing the structure during the next high water event. (Note: Structures such as vane dikes, chevrons, and windrows have no bank connection, and therefore, it is not necessary to consider scallops in the CI rating for these structures. Scallops are ranked in a fashion similar to that of dike structures. These numbers were field tested, fine tuned, and accepted by the expert panel listed in Appendix A.)

ADEQUACY OF NAVIGATION: Many factors are evaluated to determine the need for dike repair. Training structures in certain reaches of the river undergo more rapid damage than structures in other reaches. M&R plans for two dikes in identical condition may be quite different because of other factors related to each dike's location along the river. One dike within a dike field may be more important to repair than another dike within the same field, even though both may suffer the same extent of damage. Evidence may exist that a dike is likely to receive damage in the immediate future. These are abstract notions that are not readily quantifiable within the concept of a CI. The primary goal of the CI is to remove as much subjectivity from any description of condition as possible. This issue is addressed more fully in this report when the Repair Priority Index is introduced.

REVETMENT CI VALUES: Revetment CI values are described in Table 3. Robert Young, Little Rock District, first developed the revetment table. Essentially, the algorithm declares that any bare bank in a revetment structure will lead to loss of the structure and, therefore, is unacceptable. Breaks in stone slope can indicate scour, loss of toe, or loss of cover that may lead to bare bank.

The net CI for the overall condition of the structure is taken as the minimum of the calculated CIs from Table 3.

Timber Pile and Stone Fill Structures

Early dike and revetment structures were often made of timber piling with stone fill. As the timber piling rots, the structures are usually rehabilitated by simply placing more stone. Usually, the piles are not replaced. For most of these structures throughout USACE, a condition assessment can

Table 3. CI calculation.

Dike Condition Rating - CI Calculation

DOES DIKE EXIST? yes no CI_{Exist} = 100, 0 (eq. a)

IS DIKE FLANKED? yes no $CI_{Flanking}$ = 09,100 (eq. b)

LOSS OF GRADE (LG)

No loss of grade		$CI_{lg} = 100$	
0 ft < LG ≤ 1 ft	over any distance		$CI_{lg} = 75$
1 ft < LG ≤ 2 ft	over a distance ≤ 100ft	$CI_{lg} = 69$	
	over a distance > 100ft	$CI_{lg} = 55$	
2ft < LG ≤ 4 ft	over a distance ≤ 100ft	$CI_{lg} = 40$	
	over a distance > 100ft	$CI_{lg} = 39$	
4 ft < LG ≤ 6 ft	over a distance ≤ 100ft	$CI_{lg} = 24$	
	over a distance > 100ft	$CI_{lg} = 10$	
LG > 6 ft	over any distance or for any "hole"		
		$Ci_{lg} = 09$	

If the damage begins closer than 200ft from the bank, or if the damage occurs in a chute closure, deduct 15 more points; but the minimum CI_{lg} shall remain $CI_{lg} = 09$. If the dike is less than 200ft long, or is a vane (L-Head) do not subtract any additional points, the CI_{lg} numbers remain as shown above.

$$CI_{LossGrade} = MIN(CI_{lg}) \quad (eq. c)$$

Table 3 continued.

Condition Rating - CI Calculation
Bank Erosion

Scallop of *any size* begins at downstream edge of dike and extends downstream.

$$CI_{BankErosion} = 15$$

Scallops upstream *and* downstream of dike. Dike connected or covered with narrow earth plug.

    Plug wider than 40ft $CI_{BankErosion} = 39$

    Plug narrower than 40ft $CI_{BankErosion} = 20$

Scallop begins less than 20ft downstream of dike.

    Scallop less than 50ft long x 20 ft deep $CI_{BankErosion} = 36$

    Scallop 50 ft - 100 ft long x 20 ft - 50 ft deep $CI_{BankErosion} = 30$

    Scallop greater than 100ft long x 50 ft deep $CI_{BankErosion} = 24$

Scallop begins 20ft to 40ft downstream of dike.

    Scallop less than 50ft long x 20 ft deep $CI_{BankErosion} = 39$

    Scallop 50 ft - 100 ft long x 20 ft - 50 ft deep $CI_{BankErosion} = 32$

    Scallop greater than 100ft long x 50 ft deep $CI_{BankErosion} = 26$

Scallop begins 40ft to 75ft downstream of dike.

    Scallop less than 50ft long x 20 ft deep $CI_{BankErosion} = 50$

    Scallop 50 ft - 100 ft long x 20 ft - 50 ft deep $CI_{BankErosion} = 43$

    Scallop greater than 100ft long x 50 ft deep $CI_{BankErosion} = 39$

Scallop begins more than 75ft downstream of dike.

    Scallop less than 50ft long x 20 ft deep $CI_{BankErosion} = 70$

    Scallop 50 ft - 100 ft long x 20 ft - 50 ft deep $CI_{BankErosion} = 64$

    Scallop greater than 100ft long x 50 ft deep $CI_{BankErosion} = 54$

(eq. d)

        NET CI = MINIMUM(eq.a, eq.b, eq.c, eq.d) = _____

Table 3 continued.

Revetment Condition Rating - CI Calculation

Damage to Trenchfill, Mattress, or Dumped Stone Revetment

Bare bank in revetment due to erosion or propwash

Any length greater than 400 ft	$CI_{Revet} = 0$
Any length 20 ft - 400 ft	$CI_{Revet} = 9$
Any length 10 ft - 20 ft	$CI_{Revet} = 24$
Any length 5 ft - 10 ft	$CI_{Revet} = 39$

Break in stone slope, nearly over launched condition, indicating little protection stone is left.

Any length greater than 100 ft	$CI_{Revet} = 9$
Any length equal to or less than 100 ft	$CI_{Revet} = 24$

Small areas launched more than adjacent revetment, revetment generally in good condition (note: no bare bank).

Cumulative length greater than 50 ft	$CI_{Revet} = 69$
Cumulative length equal to or less than 50 ft	$CI_{Revet} = 70$

Scallops upstream or downstream of revetment.

Any scallop greater than 50ft deep	$CI_{Revet} = 9$
Any scallop greater than 100ft long	$CI_{Revet} = 9$
Scallop 51ft - 100ft length	$CI_{Revet} = 24$
Scallop 20ft - 50ft length	$CI_{Revet} = 39$
No scallop but visible erosion in bankline	$CI_{Revet} = 69$

$$\text{Revetment CI} = \text{MIN}(CI_{Revet})_____$$

Note: *Revetment structures can be miles long and be of various manner of construction. It is left to the judgment and discretion of the Districts to, if so desired, break a revetment up into smaller management sections according to construction type, material, physical location, etc.*

be made by assessing only the stone. The timber piles have almost completely rotted away, and contribute very little to the overall structural integrity. In some Districts, however, a significant number of structures are still primarily timber pile structures with stone fill. The timber piles have an essential role in the overall structural integrity if the stone is below the permanent design grade. A table for generating CIs for timber pile and stone fill structures is listed in Table 4.

First Field Test

The first field test was held on the Arkansas River at Little Rock in September 1994. Participants are listed in Appendix B. The original object of the field test was to have each inspector assess the selected structures based on their own subjective experiences. Then the group

would compare their subjective assessments to the objective CI as determined by the algorithm. However, it was immediately discovered that to make an informed and accurate assessment of the condition of the structure, even on a subjective level, first-hand knowledge of the structure's original design and performance history was necessary. The group concluded that without such knowledge one can only compare the existing structure to its as-built drawings. In-house personnel or contractors can survey the structures with rod and transit and compare existing structural dimensions to as-built drawings, but this approach is unrealistic: it would cost too much and defeat the goal of developing simple procedures. Visual observations and simple depth measurements with a stick or depth finder are sufficient for an inspector to accurately depict the described distresses. However, the inspection is best performed by those familiar with the structure's design, purpose, and performance history.

The field test proceeded as engineers recorded observations and measured distances, dimensions, and depths.

The field test clearly demonstrated two issues that needed to be addressed: structure condition and structure performance. The CI as described in Table 1 tries to address the functionality of the structure. For many structures (e.g., a miter gate) the CI will correlate strongly to functionality (or performance), and can serve not only as an accurate indicator of condition, but also as a rough measure of the structure's need for maintenance and repair. It is the consensus of the group that the CI algorithm accurately captures an objective assessment of dike and revetment condition. But when historical or current performance of the same structure is considered, the group decided that the CI as described in Table 1 did not accurately measure the structure's need for repair. A dike in perfect condition can perform poorly for a number of reasons; whereas, a dike in poor condition can perform 100% satisfactorily. The expert panel agreed that a dike and revetment grading or ranking process that ignores the consequences of failure is incomplete.

An additional concern was also raised that required a second field test. The algorithm, particularly the loss of grade distress, works well for structures on the Arkansas River. However, would it work equally well

on the larger, longer structures found on the Mississippi? A second field test to evaluate the CI was scheduled in St. Louis to answer this question.

Table 4. Condition Index for timber pile and stone fill structures.

Condition Index for Pile Dikes with Stone-fill and Pile Revetments with Stone-fill Which Have Not Been Made Permanent with Stone (Stone Is below Crp+10')						
Damages to the Revetment or Dike	Distance Stone Is below Crp +10' Elev (Feet)	Length of Damaged Area (Feet)				
		0 - 50	50 - 100	100 - 200	200 - 400	OVER 400
Piling Is Missing; Peaked Stone Is Below Permanent Grade	0 - 3	54			39	
	3 - 6	24		9		
	OVER 6	9				
Vertical Piling Is Rotted or Broken Peaked Stone Is below Permanent Grade	0 - 3	54				
	3 - 6	39			24	
	OVER 6	24	9			
Horizontal Stringers Are Broken or Missing; Vertical Piling Is Ok Peaked Stone Is below Permanent Grade	0 - 3	54				
	3 - 6	39			24	
	OVER 6	24			9	
Ties for Clumps or Ties to Stringers Are Broken; Peaked Stone Is below Permanent Grade	0 - 3	54				
	3 - 6	54		39		
	OVER 6	39	24			
Condition Index for Pile Dikes with Stone-fill and Pile Revetment with Stone-fill Which Have Been Made Permanent with Stone Having Crown Width of 5' or Greater and Top Elevation at Crp=10' or above						
USE CONDITION INDEX FOR LOSS OF GRADE IN DIKE OR REVETMENT						

6   **Repair Priority Index**

Purpose of the Repair Priority Index (RPI)

Comparing structures to as-built drawings and deducing CI values from
Table 3 is sufficient to describe the condition of dikes or revetment
consistently. The CI algorithm accomplishes consistent condition
descriptions according to the consensus of the panel of experts. However,
the group developed a separate and independent index to establish a
consistent means to rank training structures according to required
performance (or lack of performance) issues. The Repair Priority Index
(RPI) was adopted, developed, and refined to its current state by the panel
of river engineer experts that were present at Little Rock (Appendix B).

The RPI accounts for the consequences of failure (or a less-than-adequate
performance) of the structure, while considering the structure's effects on
navigation, its effects on safety in the immediate area, its M&R history, its
environmental impact, and the effects of its existence or non-existence on
neighboring structures and surrounding property. The RPI described in
Table 5 is designed to be objective, and can be consistently determined by
logical consideration of conditions described in the table. The RPI is
offered as an alternative to whatever prioritization methods may already
be in place, e.g., risk-based analyses. The RPI is designed specifically to
describe a budget work package prioritization scheme for riverine dike
and revetment structures based on safety and navigation considerations.
Its use by Districts and other Corps elements is voluntary and is intended
to complement the CI.

It is useful to note that the software developed to store inspection and
rating data, documented in REMR-OM-23, can sort structures according
either to RPI or CI.

Table 5. Stone dikes and revetments Repair Priority Index (RPI).

RPI Definitions:

1 - Structures receiving an RPI of "1" should be repaired. Allowing structure to remain in current condition will (has) cause(d) loss of a safe and dependable navigation channel; jeopardize the integrity of surrounding dikes and revetment; will cause loss of bank or damage to adjacent property.

2A - Structures receiving an RPI of "2A" should be repaired after structures receiving an RPI of "1" have been tended to. If such structures are not repaired, loss of a safe and dependable navigation channel is not imminent, but the integrity of the bank, neighboring structures, or environmental habitat is threatened. Structures receiving an RPI of "2A" may also have a *history of consistently failing* during events such as high water, floods, ice damage, tow impacts, accidents or other causes. Further, a "2A" rating may also imply that there are no neighboring dikes and revetment to maintain a safe and dependable navigation channel if this structure fails.

2B - Structures receiving an RPI of "2B" should be repaired after structures receiving an RPI of "2A" have been tended to. If such structures are not repaired, loss of a safe and dependable navigation channel is not imminent, but the integrity of the bank or neighboring dikes and revetment are threatened. These structures should be further prioritized for repair according to their REMR Condition Index.

3 - Structures receiving an RPI of "3" should be repaired after structures receiving an RPI of "2B" have been tended to. If such structures are not repaired, loss of a safe and dependable navigation channel is not imminent, nor are the integrity of the bank or neighboring dikes and revetment immediately threatened. But neglecting these structures will allow continuous deterioration.

4 - Structures receiving an RPI of "4" have been deemed not in need of repair at the time of their last inspection.

5 - Structures showing an RPI of "5" have never been assigned an RPI. The presence or lack of conditions or circumstances such as those discussed above cannot be assumed for such structures.

Second Field Test

A second field test was held in November 1995 at St. Louis Harbor Reach of the Mississippi River. The CI and RPI were tested on over a dozen structures with a variety of conditions ranging from near complete destruction to freshly rehabilitated. In every case the CI and RPI were easily determined and considered to be an adequate description of the condition and performance of the structure. The consensus regarding whether or not the loss of grade distress rating applied equally well to the

larger Mississippi structures is that small losses of stone are more significant on the smaller structures, such as on the Arkansas River, but the CIs remain relatively high, meaning that the dike is still in good condition. Minor distress on Arkansas River structures will have more effect on the CI than the same distress on a large Mississippi River dike or revetment. Therefore, the CI was determined to be equally significant on both larger and smaller structures. Participants in the St. Louis field test are listed in Appendix B.

7   Inspection Procedure, Forms, and Software

Inspection Procedure

A small craft is required to get close to the structures. It is often necessary to walk the structure or get in and under brush to inspect the bank connection or look for scallops. The stage of the river must be recorded before going out because underwater structures must be sounded. Their depths are compared to as-built drawings for loss of grade. Simply finding the structures can be frustrating. It is important to pay careful attention to your location while sounding underwater structures to facilitate deducing CIs from the drawings. Appendix D includes schematic drawings of different riverine dike and revetment configurations.

Forms

All of the engineers interviewed for this project record their observations on a blank piece of paper in the field. Some have experimented with different forms but have returned to using a simple notepad. For this reason, a simple inspection form is offered. It is a blank form with pertinent structure data preprinted by the software program that has been developed to support the CI and RPI data. This information can be useful because sometimes the structures are hard to identify and it is informative to know what was seen during the last inspection. Also printed on the form is a simple checklist of the major items to look for while on inspection:

1. Does the Dike Exist?
2. Is The Dike Flanked?
3. Is There Loss of Grade?
4. Was Sounding Data Required?
5. Condition of Bank Connection?
6. Are There Any Scallops?

A sample form appears in Appendix C.

Software

The program software manages and stores inspection data, the CI and RPI (calculated by hand), inventory data, and identification data for each structure. Sort routines use either CI or RPI as a sort key. In addition to inspection data, the program stores materials quantity estimates and unit costs needed to bring the structure up to grade and performs sums and cost estimates for contracting projects involving multiple dike and revetment rehabilitation. The program is IBM PC compatible; it was programmed on a DOS platform but operates successfully in a Windows environment. See the software user's guide REMR-OM-23 for a more detailed description of the program.

8   Conclusions

An algorithm used to produce CIs for emergent riverine stone navigation training dikes yields CIs that are objective, repeatable, and consistent with the REMR CI Scale. The CI captures a quantitative look at the current condition level and functionality of a dike and is calculated from data that are gathered during periodic visual inspections. The CI's main purpose is to serve as a uniform gauge of physical deterioration of a structure.

Five types of dike damage or distress have been identified appropriate for input into the CI algorithm. The CI reflects the presence and severity of flanking, loss of grade, dike existence and, to a degree, the amount of stone needed to repair the structure. In the case of stone dike and revetment structures, the CI is an objective measure of condition but does not correlate necessarily with an absolute need for maintenance. The Repair Priority Index assigns a ranking order for repair projects that is based on current and historical performance, safety, navigation, property, and environmental issues.

Software programs were written to support CI and RPI databases. Structures may be selected and rank ordered for M & R projects based on CI or RPI. The software also creates government estimates for M & R contracts using materials quantity estimates and unit cost inputs.

The CI and the RPI are designed to be used by river engineers as a decision-support tool for M & R planning. It is intended to be useful and easy to use. Without exception, the river engineers interviewed for this project are familiar with their structures and know, without referring to as-built drawings, whether or not their structures need added stone. For the beginning engineer, it will be time consuming and expensive to perform site surveys and compare them to as-built drawings. The experienced engineer will be able to assign a CI by knowing how much stone a structure needs. Inspections should be performed by experienced engineers for the CI and RPI to be the most efficient possible support tool.

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Appendix A
Interview Participants

Waterways Experiment Station:

Dave Derrick (CEWES-HR-RR)

Vicksburg District:

J.D. Sadler, Danny Harrison (CELMK-ED-RM)

St. Louis District:

Claude Strauser, Rob Davinroy (CELMS-ED-HP)

Tulsa District:

Mr. Curtis Weddle, Dennis Johnson, Bill Mills, Cecil Q. Hawley, Robert M. Ferguson, Perry M. Kuykendall, Ray Weger, Don Hendry, (CESWT-Robert S. Kerr Area Office), Mike Calavan (CESWT-OR-FP)

Little Rock District:
Robert Young, Craig Yada, Jim Proctor (CESWL-ED-HH)

Kansas City District:

Charles Wyatt (CEMRK-OD-MM), Ron Sargent and Mr. Tom Burke (CEMRK-ED-HR)

Omaha District:

John La Randeau (CEMRD-CO-O), Steve Earl (CEMRO-OP-M), John Remus (CEMRO-ED-HF), Richard Buchheim and Charlie Framke (CEMRO-OP-MR)

Appendix B
Technical Review Committee and Field Test Participants

Technical Review Committee

Robert Young / CESWL-ED-HH
Don Bratton / CESWL-CO-O
Wendell Myrick / CESWL-CO-RV
John Remus / CEMRO-ED-HF
Charles Wyatt / CEMRK-OD-MM
John Vento / CEMRK-ED-HR
Dennis Johnson / CESWT-OR
Claude Strauser / CELMS-ED-HP
Ross Jarrell / CELMV-CO-O
Steve Ellis / CELMV-PE-TC
Dave McKay / USACERL

Field Test - Little Rock, September 1994

Robert Young / CESWL-ED-HH
Don Bratton / CESWL-CO-O
Wendell Myrick / CESWL-CO-RV
John Remus / CEMRO-ED-HF
Charles Wyatt / CEMRK-OD-MM
John Vento / CEMRK-ED-HR
Dennis Johnson / CESWT-OR
Claude Strauser / CELMS-ED-HP
Ross Jarrell / CELMV-CO-O
Steve Ellis / CELMV-PE-TC
Dave McKay / USACERL
Stuart Foltz / USACERL
Joann Lavrich / USACERL

Field Test - St. Louis, November 1995

Claude Strauser / CELMS-ED-HP
Rob Davinroy / CELMS-ED-HP
John Naeger / CELMS-ED-HP
Dave O'Connell / CELMS-ED-HP
Brian Kratz / CELMS-ED-HP
James Brown / CELMS-ED-HP
Dave McKay / USACERL

Appendix C
Sample Form

Dike and Revetment Inspection Form   Inspector: _____

_____***River, Pool*** _____

Structure ID# _____   Other Identifying Features:

(Milepost & L,R Bank)

Structure Type: _____

(Dike or Revetment)

Dike Purpose: _____

(Bank Stab, Closure, CutOff, Kicker, L-Head, Training, Vane, Weir, Wing Dam)

Construction: _____   Design Length: _____(ft)

(Pile, Stone, Pile-Stone)

Design Crown Width: _____(ft) Design Height _____(ft) At ___ crp

Last Rehab Date: _____(DDMMYY)

Condition Inspection Observations:

Dike Exist?____ Is Dike Flanked_____ Loss of Grade?_____ Sounding Data?_____ Bank Connection?_____ Scallops?_____

Appendix D
Dike and Revetment Nomenclature and Configurations

Dike
A stone or pile (or stone-pile) structure that is most often connected to the riverbank and built generally perpendicular to the flow in the channel. The dike promotes higher flow velocity at the riverward end, and slower water velocities at the bank end, thus promoting better sediment transport in the channel as well as accretion near the bank. Often called a training dike or spur dike, it is used for both channel improvement and bank stabilization. Sometimes dikes are notched to enhance environmental aspects downstream of the dike. (Note - Dike nomenclature varies across some districts, eg. a spur dike is the same as a training dike in many Districts, however in other districts a spur and a kicker dike carry the same meaning.)

Revetment
A structure that is generally built into or close to the river bank and generally runs generally parallel to the flow of the river. It can be of varying construction but is generally made of placed stone, rip rap, timber pile with stone fill. A revetment's primary function is bank stabilization.

L-Head
A training dike with a perpendicular dike structure attached at the channel end creating an L shape. The attached dike structure is usually lower in elevation (e.g. 1-5 feet). The purpose of this structure is to control scour patterns at the training dike's riverward end for channel improvement.

Baffle Dike
A dike built behind (bankward) and perpendicular to an extended-revetment or other dike structure whose alignment is roughly parallel with the channel flow. The baffle dike can lend structural support to the revetment-dike, as well as protect the bank if high water tops the revetment-dike. The baffle dike is usually connected to the bank and perpendicular to the revetment-dike. A baffle dike is used primarily for bank stabilization.

30

Bendway Weir A weir placed in an outward river bend, usually attached to the bank, angled upstream (roughly 30 degrees relative to the flow's perpendicular). This structure is used for channel improvement, but also pulls water away from bank, promoting bank stability.

Bullnose A U-curved dike structure which is built on the upstream end of an eroding island. The horseshoe shape of the bullnose is used to keep the downstream island banks from eroding. The horseshoe fits over the upstream end of the island and is connected to it on either side.

Chevron Similar to the U-shape of a bullnose, a chevron is built away from an island, generally in the side channel created by an island. Chevrons divert water to the main channel and also roughen the water for environmental purposes in the side channel. A chevron dike provides both channel improvement, and environmental benefits.

Closure Sometimes called a chute closure, a dike structure reaching from the edge of an island to the edge of the river bank. A closure is used to divert water back into the main channel for channel improvement.

Hard Point A short perpendicular dike which is often used in groups. Hard points are placed along the landward bank of a chute or slough. Hard point is used for bank stability, and to promote environmental quality.

Kicker A dike structure that is often the extension of a revetment where the bank tails away from the main channel. It is placed generally parallel to the channel. During normal flow a kicker guides water back towards the main channel. During high flow, if a kicker is topped, negative effects on the adjacent bank can be suffered. (Note: a baffle dike is often used to counter these effects.) A kicker is used for channel improvement and bank stabilization.

Spur Dike Most often meant to mean a training dike, sometimes referred to as a kicker dike.

MRS MRS, stands for Multiple Roundpoint Structures. Rather than placing a single continuous training dike, regularly interspersed mounds of stone are placed to act as a permeable stone training dike. A group of MRS is used to improve the channel and roughen the water for environmental effects. Typical dimensions for St. Louis District MRS are:

Diameter: about 40 feet

Distance between the perimeters: about 50 feet

Structures per group: 5-10

Off Bankline

Revetment   A dike-like structure that is built off the bankline, but generally closer to the bank that vane dikes. An off-bank structure is parallel to both the bank and the flow. It is generally used for bank stabilization, and to maintain environmental quality. This structure is usually built in groups and may be thought of as an L-Head without the training dike.

Toe Dike   A dike usually built along the toe line of a revetment (parallel to flow) but is also used to "close in" a severe scallop or other damage caused by bank erosion. This structure is used for bank stabilization by preventing downstream scour of the bank or revetment.

Training

Dike   See "Dike"

Vane Dike   A dike structure which is detached from the channel bank, and is either parallel to the flow or at a slight angle to the flow. It is associated more with the channel than the bank (as would be the case in an off-line bank revetment). This structure is used for channel improvement.

Weir   A weir is an underwater dike but usually larger than a dike. Sometimes called an underwater dam. This structure is used for channel improvement.
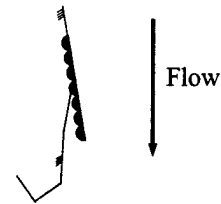
Wing-Dam   A wing-dam is a submerged training dike used for channel improvement.
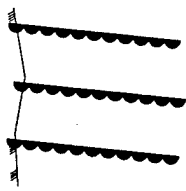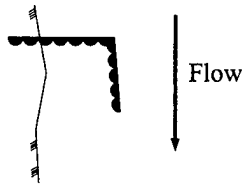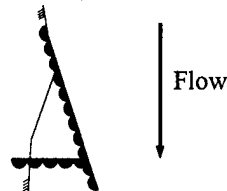
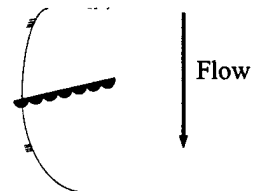**Training or Spur Dikes, Wingdams**
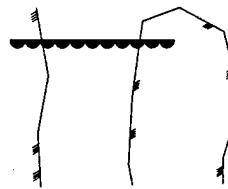
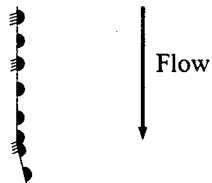**Chute Closure**

Kicker or Spur Dike, Extended Revetment
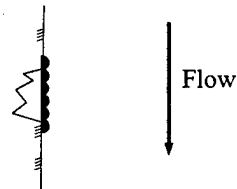
Flow

L-Head Dike, or Spur with L-Head dike
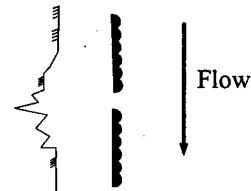
Flow

Extended Revetment or Kicker with Baffle
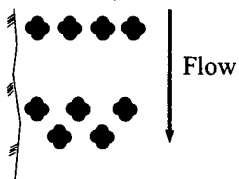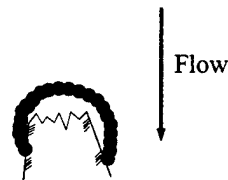
Flow

Bendway Weir

Flow

Hardpoints

Flow

Toe Dike or Windrow

Flow

Off Bank Line Revetment

Flow

Multiple Round Point

Flow

Bull Nose

Flow

Chevron Dikes

Flow

Vane Dikes

Flow
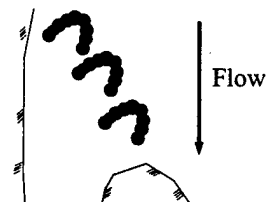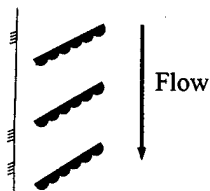
REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE September 1998	3. REPORT TYPE AND DATES COVERED Final	

4. TITLE AND SUBTITLE REMR Management Systems - Navigation Structures:	5. FUNDING NUMBERS CWIS 32672
6. AUTHOR(S) David T. McKay	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005	8. PERFORMING ORGANIZATION REPORT NUMBER 98/21

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Headquarters, U.S. Army Corps of Engineers ATTN: CECW-EE 20 Massachusetts Ave. NW Washington, DC 20314-1000	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report describes a simple algorithm that provides a quantitative description of the condition of riverine stone navigation training dikes and revetment. The quantitative description, called a condition index (CI), is incorporated into a REMR Management System for stone navigation training dikes and revetment. The CI is an indicator of a structure's condition and, to some extent, its functionality. The CI is obtained from an algorithm that uses field inspection data as input and is designed so that it provides consistent, repeatable, uniform results.

The fundamental goals of the REMR Management System are to establish Corps-wide inspection uniformity and to establish common definitions of condition so that more effective communications concerning condition can be made. REMR Management Systems use uniform condition inspection techniques that emphasize visual, inexpensive, and efficient methods of data gathering.

The Corps oversees the maintenance and repair of thousands of river bank stabilization structures and maintains an inventory of nearly 11,000 riverine training dike structures. This report addresses the condition assessments of existing stone dikes and stone dikes that will be constructed in the future.

14. SUBJECT TERMS REMR management system civil works navigation structures operation and maintenace dikes		15. NUMBER OF PAGES 40
		16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR